Mitigation Strategies for Dissolved Phosphorus Transport: Emerging Science

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Can We Avoid Unintended Consequences? Agricultural Systems are Leaky!

Farmers provide society with food, feed, fiber, and fuel with economical efficiency!

How do we equilibrate between economic efficiency and ecological impact?

Requires a shift in scale:
More efficient agronomics need to be better combined with practices that provide healthier soils and approaches that effectively manage LANDSCAPES and their natural variability.

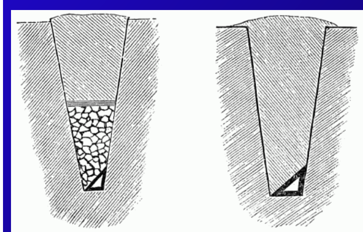
Integrate knowledge about landscape variability, hydrology, and ecosystem processes into production agriculture.

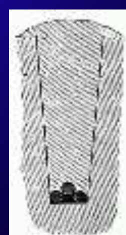
Accept that agricultural systems do leak – incorporate upland, EOF, and downstream approaches to minimize the impact of agriculture.

Excerpts from *Farm Drainage*, by Henry French published in 1860:

- "The agriculture of Ohio can make no farther marked progress until a good system of under-drainage has been adopted." - John H. Klippart, Esq., the learned Secretary of the Ohio Board of Agriculture

- "One of two things must be done by us here. Clay predominates in our soil, and we must under-drain our land, or sell and move west." - A writer in the *Country Gentleman*, from Ashtabula County, Ohio





Necessity of Tile Drainage

25% of cropland in US and Canada could not be farmed without tile drainage (Skaggs et al., 1994)

- soils with the greatest inherent production potential

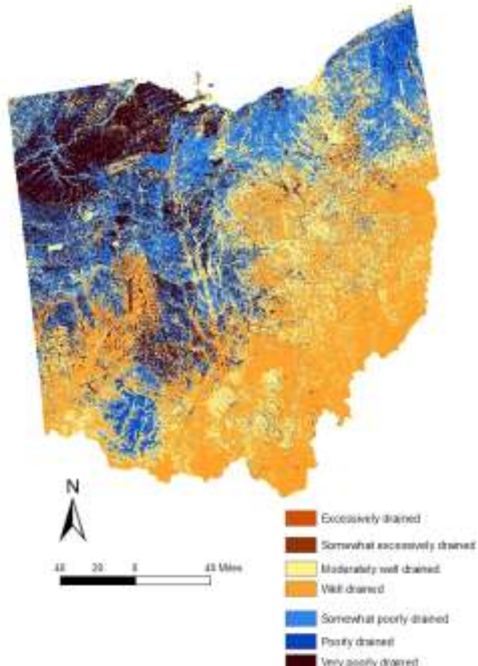
Tile Drainage (Fausey et al., 1987):

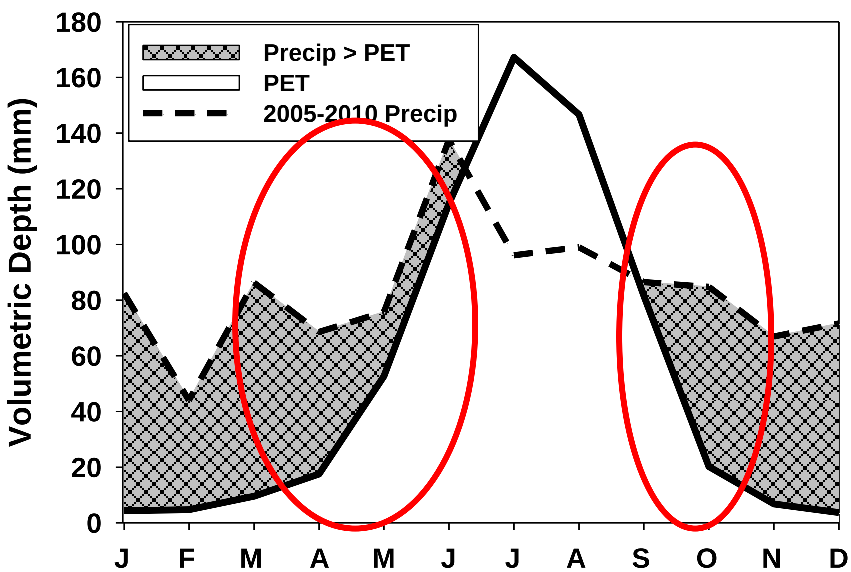
- provides trafficable conditions for field operations
- promotes root development by preventing exposure of plants to excess water

Why Drainage is Required

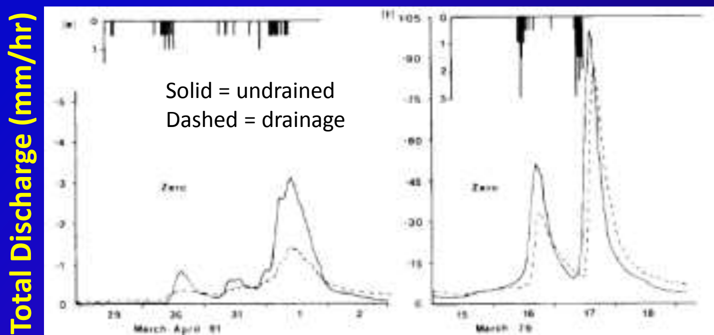
- glacially derived, fine textured soils

- low gradient (flat)





Effect of Drainage on Discharge



(Robinson and Beven, 1983)

Sandusky, Ohio (Schwab et al., 1963)

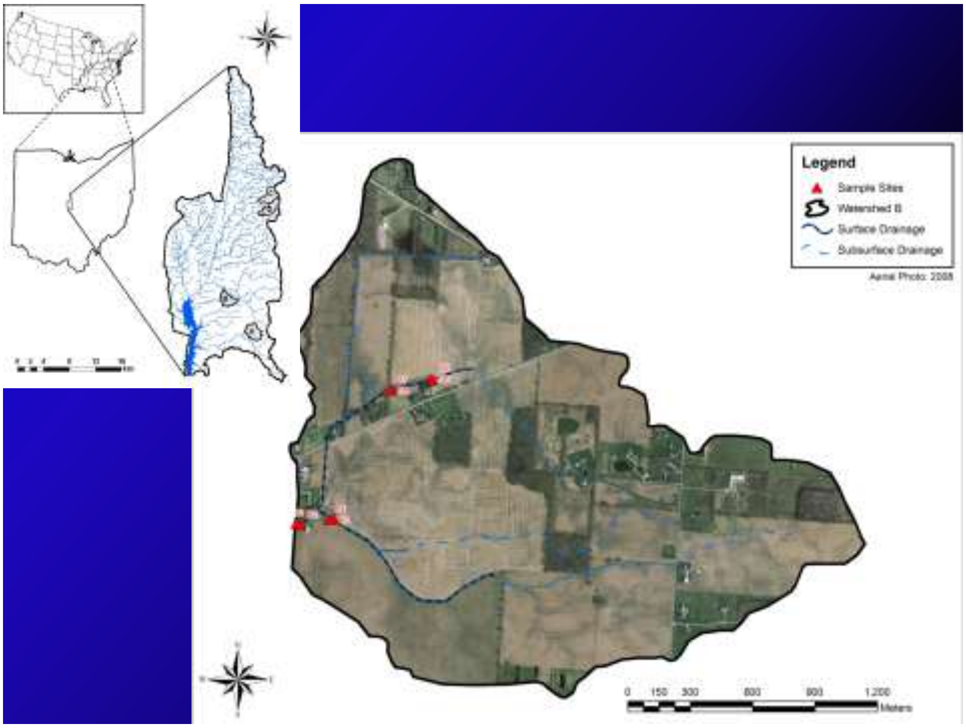
Discharge from replicated 0.23 ha plots, Toledo silty clay

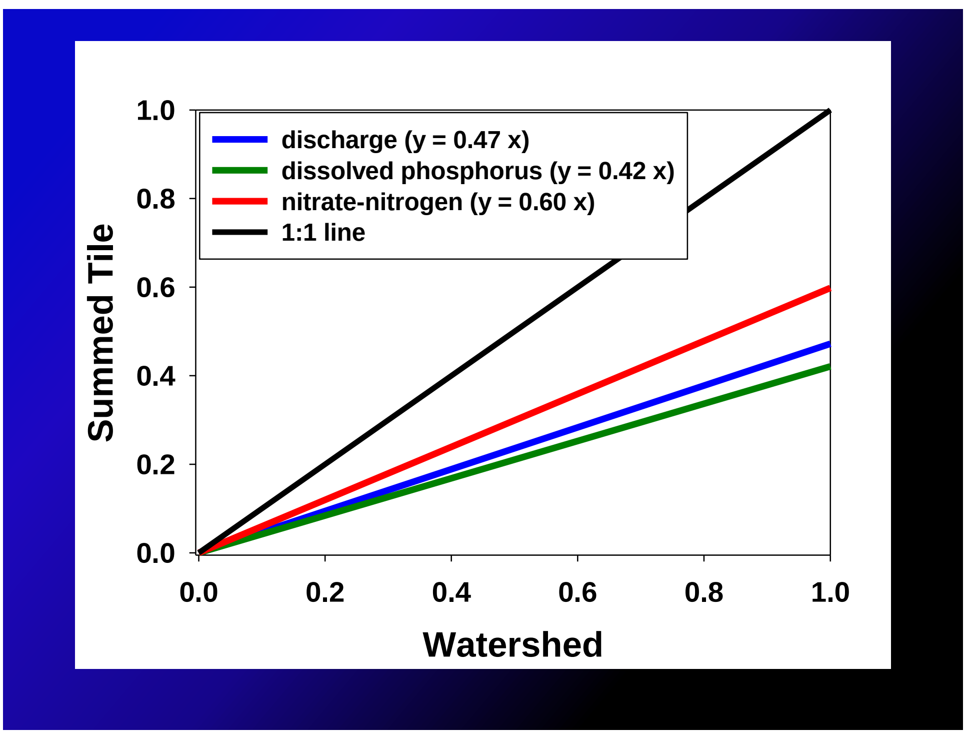
(March to September)

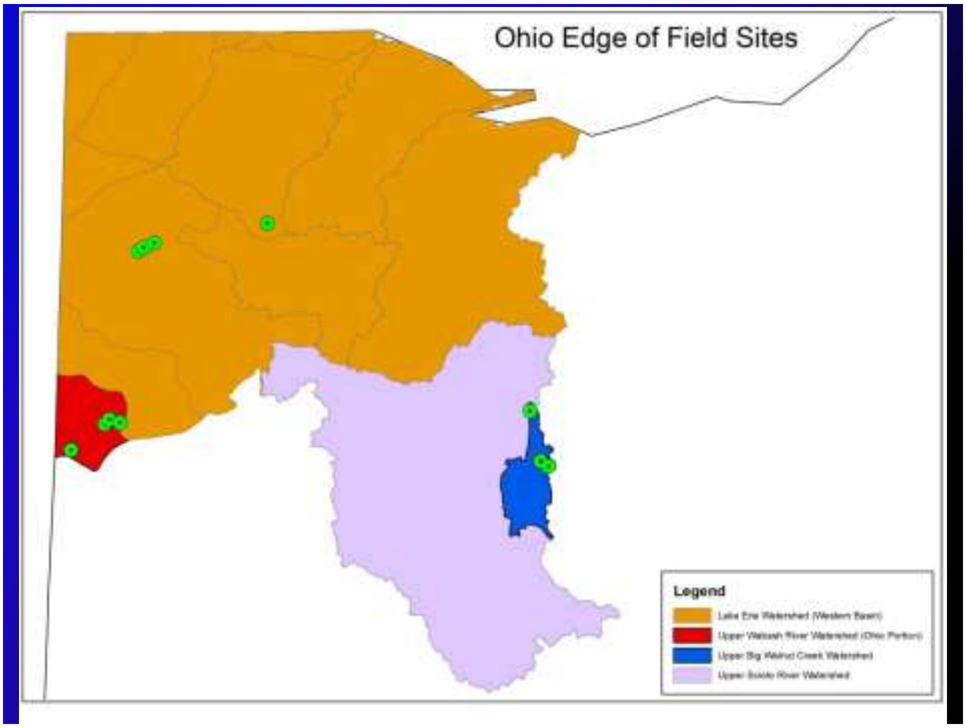
Surface drained only (81 mm)

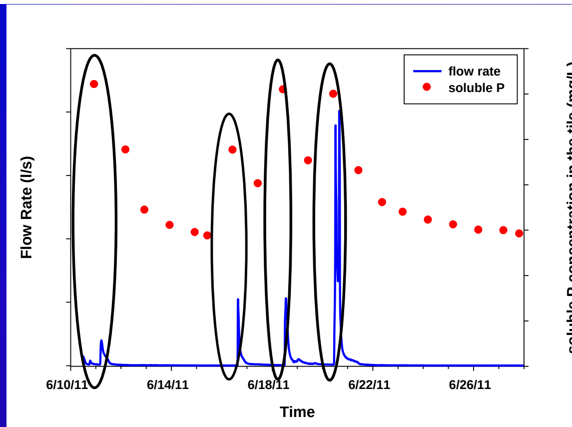
Surface and subsurface (88 mm)

Current Research


Legend
Sample Sites
Watershed B
Surface Drainage
Subsurface Drainage
Aerial Photo: 2008
0 150 300 600 900 1,200
Meters


discharge (y = 0.47 x)
dissolved phosphorus (y = 0.42 x)
nitrate-nitrogen (y = 0.60 x)
1:1 line
Summed Tile
Watershed
0.0
0.2
0.4
0.6
0.8
1.0

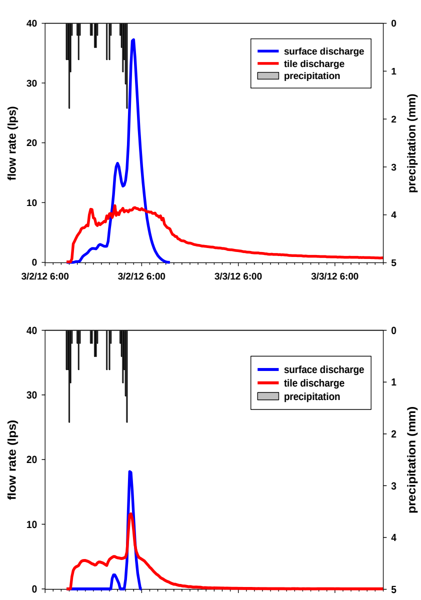

Ohio Edge of Field Sites
Legend
Lake Erie Watershed (Western Basin)
Upper Wabash River Watershed (Ohio Portion)
Upper Big Walnut Creek Watershed
Upper Scioto River Watershed

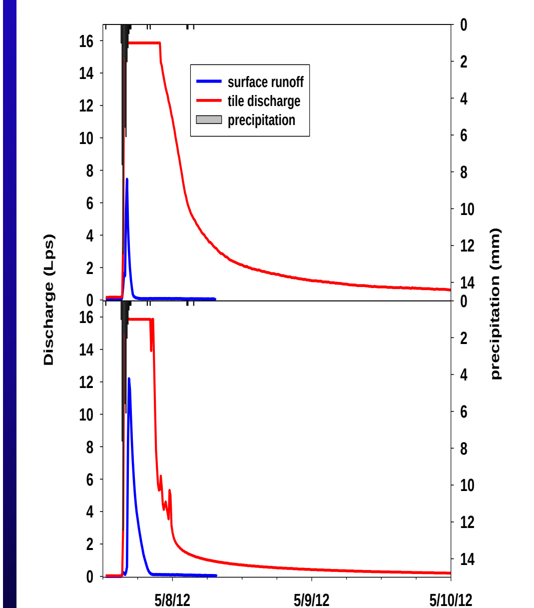


Chemograph of soluble P concentration in tile flow (Mercer County, OH)

Positive correlation between peaks in concentrations and tile discharge indicate fast flow processes (preferential flow) and connection to surface sources

Two different tile systems with different responses





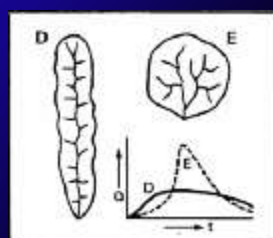
0.5 inch rainfall

1.25 inches rainfall

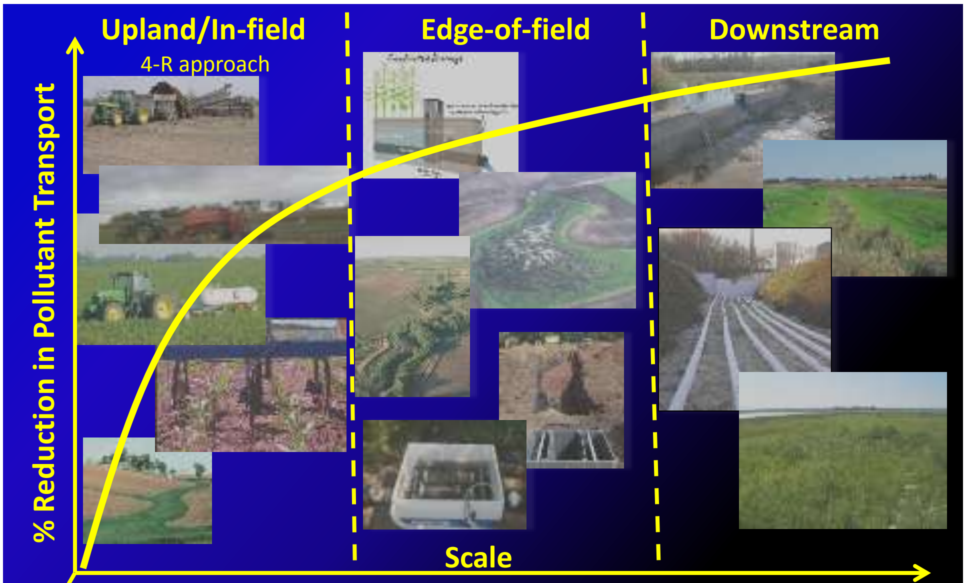
Mitigation Strategies

What Determines Watershed Condition and Response?
How Do We Measure and Monitor?
How Do Watersheds Function to Transport and Process Pollutants?

Uniqueness
- Landscape and geomorphology (drainage density, shape factors)
- Management
- Soils and geological deposits
- Climate
- Hydrologic alteration (drainage, impoundments)



Complexity
- Lag time
- Seasonality
- Land use change
- Riparian function and processes
- Interacting cycles of water, carbon, and nutrients



What is the most effective scale to address water quality? How do we avoid tradeoffs among pollutants? How does it depend on the ecoregion? How do we convince landowners to look at their individual fields in a larger environmental context?

Strategies for Addressing Agricultural Induced Phosphorus Transport

Upland Management
- 4Rs
- Interruption of connection to surface

Structural Hydrologic Control
- Drainage water management
- blind inlets

Filtration
- End-of-tile and in-stream
- Enhanced bioreactors

Edge-of-field
- Buffers
- wetlands

Ditch Design and Management
- Two stage, natural, and over-wide ditches
- Dredging
- Vegetated channels

Upland Management (4 Rs)

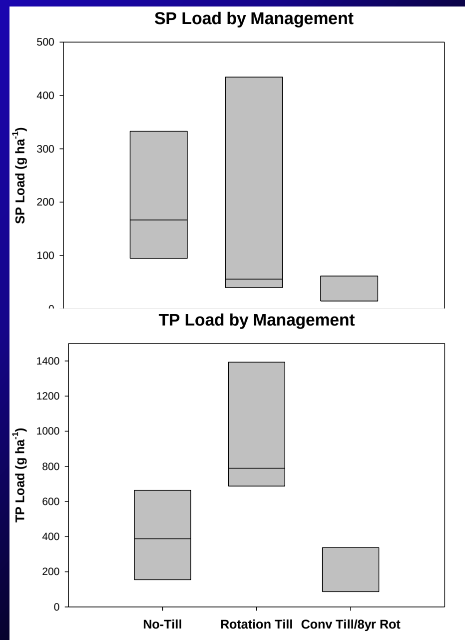
- Rate
  - adhere to soil test recommendations
  - apply only what is needed in crop year; avoid multi-year applications (Algoazany et al., 2007)
- Source
  - manure vs. commercial (Phillips et al., 1981)
- Placement
  - incorporation
  - precision application
  - banding vs. broadcast
- Timing
  - be cognizant of weather predictions and avoid application prior to rainfall
  - avoid winter time manure applications – winter applied manure had greatest concentrations of dissolved P in tile effluent (Phillips et al., 1981)

Potential Practices to Investigate

- Cover crops
- Banding vs broadcast
- Spring vs fall vs split application
- Incorporation
- Deep injection
- Tillage vs no-till
- Tri state recommendation vs reduced rate
- Manure vs commercial fertilizers
- Controlled traffic and variable rate application
- Other

Cropping & Tillage

- More frequent, lower rates of fertilizer result in less loss
- Longer rotations lose less P
- No-till may result in > SP loss, but must balance that with < TP loss
- More P lost with corn (due to P applications)
- Tillage increases buffering capacity and disrupts macropores



Provided by Doug Smith
USDA-ARS, West Lafayette, IN

Fertilizer Source, Placement, and Rate

- DRP conc. peaks occurred after broadcast appl. (Turtola and Jaakkola 1995)
- Greater appl. rate and applying P after crop harvest had greater soluble P transport in tile (Algoazany et al 2007)
- Sites where P was applied every 2 years had greater P concentration in tile drainage (Algoazany et al 2007)
- Poultry and swine manure generally had greater proportions of DRP compared to dairy manure and commercial fertilizers (Kinley et al 2007)

Promote soil biological diversity

- Soil organisms control transformation between inorganic and organic P forms (Frossard et al., 2000; Illmer et al., 1995)
- Addition of microbial energy sources increased mobility of P by 38 times (Hannapel et al., 1963a)
- Mobilization of P by microbial population was most important factor in P transport (Hannapel et al., 1963b)

Structural Hydrologic Control

Drainage Water Management

Blind Inlets

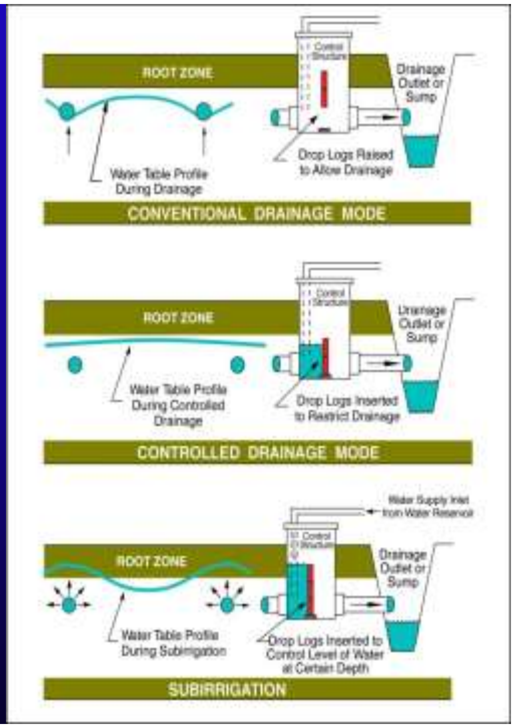
Drainage Water Management

- reduced total phosphorus losses in NC by 35% (Evans et al., 1990)

- DRP losses reduced by 63% and TP losses by 50% in MN (Feser et al., 2010)

- 85% reduction in TP losses from small plots in Sweden (Wesstrom et al., 2001)

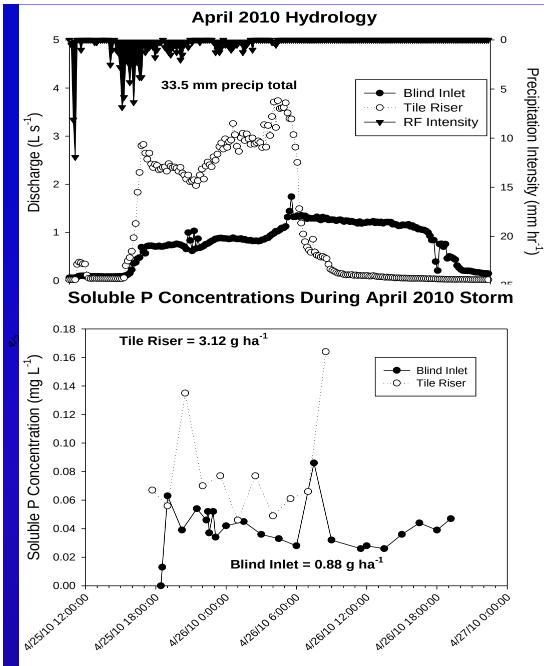
- 18% reduction in median DRP concentrations in Ohio from 8 paired fields (unpublished data from Norm Fausey)



Blind Inlets

Must be a practice farmers will implement

- **Reduce <u>sediment</u> & <u>phosphorus</u> loads**
- **Minimize loss of productive land**
- **Allow farm traffic (don't like risers)**
- **Minimal/easy maintenance**
- **Approved for cost share**
- **Effectively drain landscape**



Percent Reduction (blind inlet vs. tile riser)

	2009	2010
Soluble P	64	72
Total P	52	78

Provided by Doug Smith
USDA-ARS, West Lafayette, IN

Filtration

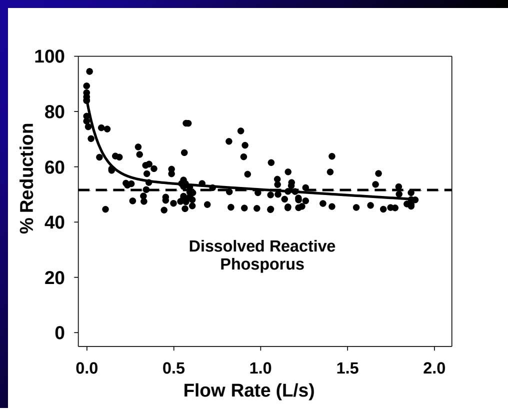
End-of-tile and in-stream

Enhanced bioreactors

End-of-Tile Filters

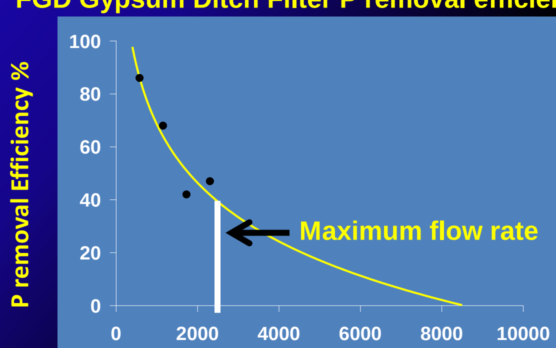
Laboratory and Field Results
- 50% reduction in DRP concentrations and loads across 3 flow rates

Constraint(s)
- Flow Rates



Ditch filters

FGD Gypsum Ditch Filter P removal efficiency



Flow Rate Through Gypsum Filter L Day^{-1} m^{2}

Provided by Peter Kleinman
USDA-ARS, State College, PA

In-stream or end-of-tile treatment summary

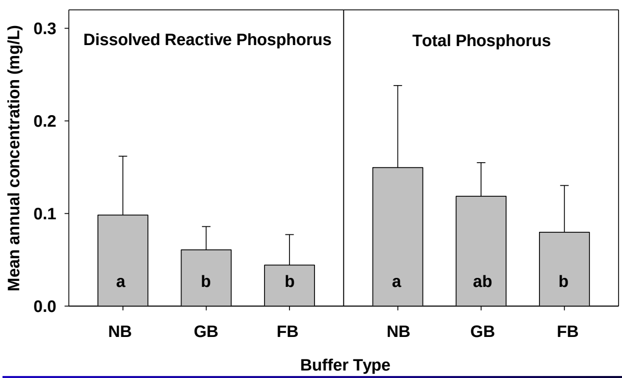
- approximately 70% reduction in DRP over 2 years in New Zealand (McDowell et al., 2008)
- > 70% of DRP in milkhouse wastes removed with steel slag (Bird and Drizo, 2010)
- DRP concentrations reduced by 50 to 99% using in-stream gypsum (Penn et al., 2010)
- 50% reduction in DRP concentrations and loads using end-of-tile filters (King et al., 2010)
- bioreactors enriched with steel slag (Brown et al., in progress)
- flow rate is limiting factor both in-stream and end-of-tile systems

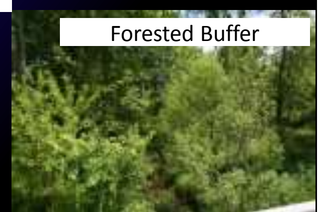
Edge-of-field

Buffers

wetlands

Buffers





Mean annual (2006-2010) stream side nutrient concentrations for dissolved reactive phosphorus and total phosphorus for streams with no buffers (NB), grassed buffers (GB), and forested buffers (FB). (unpublished data in UBWC provided by Kevin King).

Buffers

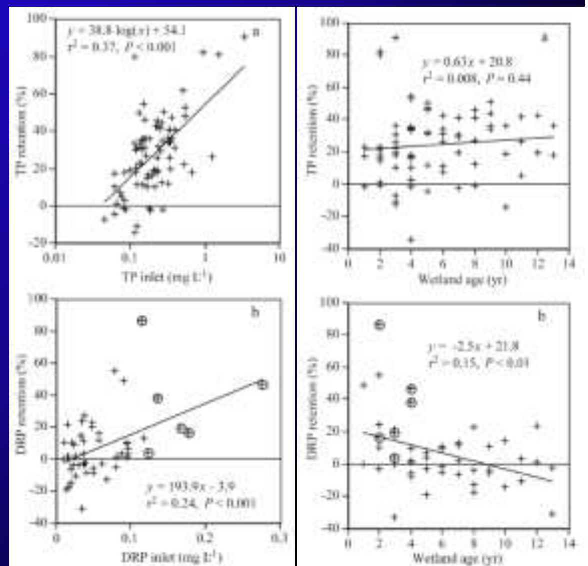
- Many buffers along streams serve predominately as setbacks
- Current buffering in Indiana watershed reduces TP loading by ~8% but could increase to 50% reduction if all field buffered (Mega $$$)
- FB > GB > NB
- Primarily addresses surface transport

Wetlands

Braskerud et al. (2005):

- 17 constructed wetlands
- Sweden, Norway, Finland, Switzerland, USA (Illinois)
- Surface area (400 to 10000 m²)

- Limited in addressing large flows



Braskerud et al. (2005)

Ditch Design and Management

- Two stage, natural, and over-wide ditches
- Dredging
- Vegetated channels

Agricultural Ditch Design Approaches

Trapezoidal Design

Two-Stage Design

Self-Forming Design

Provided by Jon Witter
Ohio State University

Two-Stage vs. Trapezoidal Design

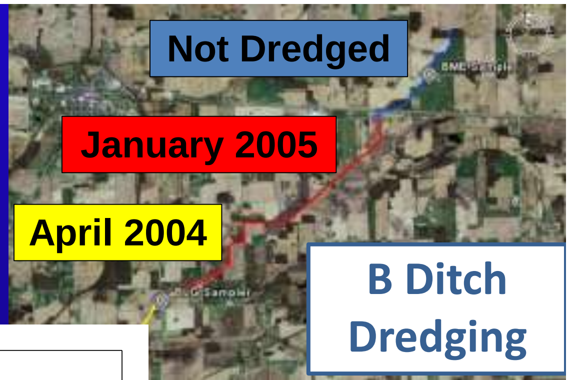
- DRP not as variable; reduced in 3 streams
- Using paired data: two-stage reduced SRP concentrations (paired t-test, p=0.04)

Site	SRP (μg l^{-1}) mean (SE)	
	Trapezoid	2-stage
Shatto	39 (0.6)	25 (0.4)
Ransbottom	67 (2.1)	59 (1.7)
Creel	25 (2.7)	9 (0.3)
Crommer	19 (1.3)	22 (1.2)
Ridenour	43 (2.0)	50 (2.0)
Powers	15 (0.3)	14 (0.3)

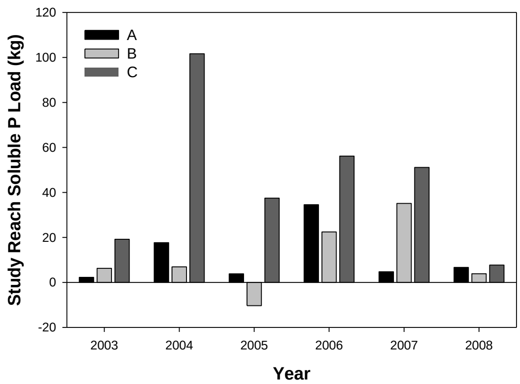
Two-stage reduced SRP concentrations, but site dependent

Tank, Davis et al. unpublished data
University of Notre Dame

Dredging



In-situ P loads for monitored study reaches



Provided by Doug Smith
USDA-ARS, West Lafayette, IN

Vegetated Drainage Ditches

Water / nutrient / sediment mixture amendment flow:
600 gallons/minute for 7 hr

Load Reduction (%)

	Vegetated
DIP	99
TP	86

Provided by Robbie Kroger (MSU)

Ditch Design and Management Summary

- vegetated drainage ditches or linear wetlands reduced DRP in growing season by 61% in MS (Kroger et al., 2008)
- two-stage ditches
  - promotes denitrification in the benches (Roley et al., 2011)
  - preliminary findings suggest greater than 30% reduction of DRP in 3 ditches while 3 other ditches had no reduction (Tank et al., unpublished data)
- dredging reduced intermediate term (approx 1 year) total and soluble P losses (Smith and Huang, 2010)



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How to Implement

- Market approach

  Supply/Demand: increase price of fertilizer to limit unnecessary or insurance applications

  Trading: accepts status quo and does not consider spatial location

  Watershed based Co-op (Novak, 2012)

- Incentives and Voluntary Implementation - somewhat effective but only affect maybe 20% of land and maybe not critical source areas

- Regulation - may work but don't necessarily have resources to implement and greater societal problems will arise (i.e. food prices will soar)

"Everybody talks about environmentalists, well, I do not really think very much of the environmentalists, per se, because I feel like I am one. I am involved with it everyday, I do it everyday, I do not go to work in an office and do things like that. I feel like we are the active environmentalists, not environmental activists." **(Illinois Farmer/Producer quoted in Urban, 2005)**

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